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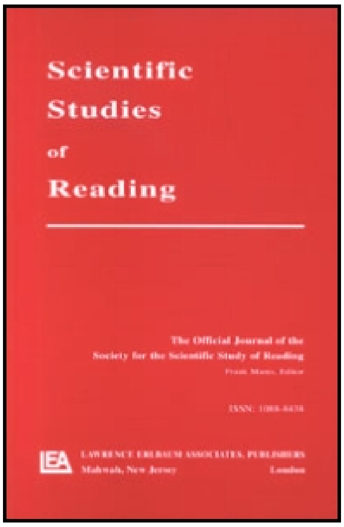

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Effects of Computer-Assisted Training of Blending Skills in Kindergartners

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Training prereaders in phonological skills has been shown to facilitate the acquisition of literacy skills. The question was raised whether it would be possible to use computer-based exercises to increase blending skills in Dutch kindergartners who had not yet received reading instruction. A package of experimental computer exercises was used in which word materials, instructions, and comments were provided through high-quality digitized speech. Twenty-five children received specific training in blending separate letter sounds into words during a 12-week period; their classmates ($n = 28$) received training in vocabulary using the same computers and program; yet another control group ($n = 45$) from separate classes did not have access to the computer programs. All children appeared to improve in blending skill, more so in classrooms in which teachers regularly provided various activities to promote phonological skills. However, the results also reveal a significant additional effect due to the use of the computer program. Transfer effects of the computer-based exercises to decoding skill were found after a few months of beginning reading instruction.

Awareness of phonemes may be helpful in mastering an alphabetical writing system because graphemes systematically correspond to phonemes. Indeed, many correlational and longitudinal studies have reported that phonological awareness is the most potent predictor of later reading success, more so than intelligence ratings and general language ability (Adams, 1990; Stanovich, 1986). This suggests that phonological skills are causally related to the development of reading skill. However, in some studies, phonological skills were measured at a time when children were already learning to read; in other longitudinal studies, early indicators of emergent literacy were not always included. An analytic attitude toward the sound structure of spoken words may in fact be triggered in some children by experience

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with the alphabetic writing system. Phonological awareness could be a cause and a consequence of reading acquisition. To resolve this issue of reciprocal causal relations between phonological awareness and reading ability, experimental manipulation is needed.

Several studies involving explicit training of children in phonological awareness have been published (e.g., Ball & Blachman, 1991; Blachman, Ball, Black, & Tangel, 1994; Borstrøm & Elbro, 1997; Bradley & Bryant, 1983, 1985; Brennan & Ireson, 1997; Byrne & Fielding-Barnsley, 1995; Cary & Verhaeghe, 1994; Castle, Riach, & Nicolson, 1994; Defior & Tudela, 1994; Foster, Erickson, Foster, Brinkman, & Torgesen, 1994; Hatcher, Hulme, & Ellis, 1994; Lie, 1991; Lundberg, Frost, & Peterson, 1988; McGuinness, McGuinness, & Donohue, 1995; Schneider, Reimers, Roth, & Visé, 1997; Tornéus, 1984; Tunmer & Nesdale, 1985; Uhry & Shepherd, 1993). Although there are important differences among studies in design and procedures, they all seem to reach the general conclusion that phonological awareness can be taught and that training in phonological awareness is highly beneficial for acquiring basic literacy skills. Only a few studies focus on training of phonological skills in prereading kindergartners without also introducing letter–sound relations or other components of beginning reading instruction (Cunningham, 1990; Foster et al., 1994; Kozminsky & Kozminsky, 1995; Lundberg et al., 1988; Schneider et al., 1997). This study was carried out to add to existing evidence for the conjecture that training of prereaders in phonological awareness does indeed significantly affect later acquisition of reading skills.

The first purpose of this study was, however, to evaluate an alternative way of training phonological awareness in kindergartners—namely, using computers. Use of computers in education has both benefits and disadvantages (see, e.g., Reinking & Bridwell-Bowles, 1991). Important advantages are that it does not significantly increase the work load for teachers, it allows them to continue their regular classroom activities, and the program can be used at any time throughout the school day. Of course, use of a computer program also has some drawbacks. Some initial instruction is needed for both teachers and children to use the programs appropriately, and overt segmentation responses of children cannot (yet) be asked for in the computer-assisted training. Nevertheless, considering the positive results in previous research, it seems worthwhile to investigate whether training of phonological skills in kindergartners can be accomplished through the use of computer-assisted instruction. Promising results using computer-assisted exercises with (digitized or synthetic) speech output have already been obtained in several studies (e.g., Barker & Torgesen, 1995; Elbro, Rasmussen, & Spelling, 1996; Foster et al., 1994; Reitsma, 1988; Spaai, Reitsma & Ellermann, 1991; Van Daal & Reitsma, 1993).

Foster et al. (1994) specifically demonstrated that computer-assisted instruction and practice could be quite successful in increasing phonological awareness skills in kindergartners. In two experiments, Foster et al. provided computer-administered instruction and practice to kindergartners. Both experiments clearly indicated a significantly larger improvement on phonological awareness measures for the experimental group than for a control group that received no intervention at all. The control group children received their normal kindergarten curriculum. However, to evaluate the specificity of the effects of phonemic awareness training, a proper control group is needed, and the classroom environment should be taken into account. Because teachers are likely to differ in the extent to which they perhaps also provide specific exercises to stimulate the development of phonemic awareness, one should control for these activities in both the experimental and the control groups. An adequate design to study the effects of training, then, would be to randomly assign the experimental and control participants within the same teacher groups and also to provide the control participants with some nonspecific experimental exercises as well. With a computer program delivering exercises to individual pupils, random assignment of children to treatment or control conditions is quite feasible. This design was adopted in this study.

A second goal of the study was to determine the effects of this training on later reading performance. Foster et al. (1994) did not report on the subsequent reading achievement of the kindergartners who had received the computer-administered training in phonological awareness. The question in the present experiment, therefore, is whether training in phoneme synthesis via the computer produces long-term effects on subsequent reading achievement. One could argue that it is specifically blending skills that enable the acquisition of beginning reading skill (cf. Perfetti, Beck, Bell, & Hughes, 1987). Indeed, several training studies both in the laboratory and in the field have provided strong evidence that phoneme synthesis and symbol–sound knowledge are corequisite, causal factors in reading acquisition (for a review, see Share, 1995). No solid evidence is available about the effects of exclusively training blending procedures in kindergartners. Skillful performance on a blending task may reflect a well-developed awareness of the sound structure of words and may contribute to improvements in segmentation skill as well as form a suitable basis to later learn the mappings of symbols to sound in learning to read. On the other hand, one cannot readily reject the conjecture that, although blending requires the manipulation of phonological units, it does not obligate independent and explicit analysis of the phonological structures and therefore may be of limited value in adequately advancing phonological skill development in children before they learn to read.

A third purpose of the present experiment was to test whether reported effects of training in phonological skills can be replicated in a country with a different educational context. Findings in a given country cannot readily be generalized to the educational context in other countries. For example, the age at which children enter kindergarten and, more important, the age at which they enter elementary school and begin to receive reading instruction differ among countries. There are also differences in orthography; or, more important, the consistency with which letters are related to sound segments differs from relatively irregular (e.g., English, Danish) to relatively regular (e.g., German, Dutch). Training in phonological skills before one begins instruction in reading could be more beneficial when the spelling–sound correspondences are relatively regular. Further, an important but often neglected aspect is the extent to which regular teaching in Grade 1 already involves the explicit training of phonological skills. For example, the most common methods used to teach beginning reading in the Netherlands incorporate explicit instruction in phonological skills such as adding, omitting, substituting, and rearranging phonemes. If instructional programs already include training of phonological skills, then it is less likely to expect substantial and long-lasting effects of pretraining of phonemic skills on subsequent acquisition of literacy skills.

In this study, kindergartners practiced phonological skills with an emphasis on blending using a computer-assisted training program with no concurrent teaching of letter–sound correspondences or word reading. To control for special attention effects and the influence of teaching activities, a randomly selected control group from the same classrooms received vocabulary training using the same computer program. Another control group from different schools received no special treatment. Six months before children entered Grade 1, in which formal teaching of reading began, all participants were pretested on phonological segmentation and blending skills, vocabulary, knowledge of letters, and reading skill. Then, the 12-week computer-assisted training period began. Through regular classroom observations and teacher questionnaires, the educational context was evaluated in order to check on additional teacher-led activities devoted to the promotion of phonemic awareness. After the training and shortly before summer break, all participants were tested again for phonological segmentation and blending skills. It was hypothesized that the experimental training group (as compared to the two control groups) would show greater gains specifically in blending skill. After 10 and 18 weeks of formal teaching in reading in Grade 1, all children were tested on decoding performance, and it was expected that the effects of training in blending would transfer to differences in decoding skill between the experimental conditions.

METHOD

Participants

The children came from 12 kindergarten classes in four different local public elementary schools. The 12 classes (average group size = 24) included children of different ages (4 years being the youngest). Teachers expected the eldest 161 children to go to Grade 1 classes after the next summer holidays; there they would receive their first formal instruction in reading and writing. Letters were sent to the parents of all 161 children explaining the purpose of the study and asking permission for the children to take part. All parents or caretakers gave permission.

Most of the 161 children (68%) had Dutch as their native language; the rest were from families originating either from Suriname (18%) or from other countries (e.g., Morocco, Turkey). Although proficiency in Dutch varied, all but 3 children had a fair command of spoken Dutch. The data of these 3 participants were ignored. There was considerable attrition during this 1-year longitudinal study. Thirty-nine children either moved to other schools or were absent for a relatively long time at one or more moments of testing. Further, the data of 21 children who at the time of the pretest could already recognize three or more words from a list of 10 simple consonant–vowel–consonant (CVC) words and who could identify more than 12 letters correctly (either by name or sound) from a list of 27 lowercase letters were excluded. The remaining 98 participants included 46 girls and 52 boys (mean age = 5 years, 10 months; age range = 62 to 83 months).

The parents or caretakers were interviewed with questionnaires regarding the language spoken at home, parents' jobs and education levels, number of books at home, reading habits, amount of storybook reading, possible phonological awareness preparation, and possible reading instruction by parents.

The sample of 98 participants was divided into three experimental groups. One school with 5 classes served as a normal control group ($n = 45$) in which no computer exercises were offered; within each of the 7 other classes in the three remaining schools, children were assigned to either the experimental computer group or the computer control group. Assignment to the latter two conditions was pseudo-randomized. Children were first ordered in rank with respect to performance on phonological pretests, and then members of subsequent pairs of children were randomly assigned to conditions. The conditions did not appear to be significantly different on any of the variables, including age, sex, socioeconomic status, vocabulary, and phonological skill.

Materials and Procedures for Testing

Pretests. In January, several tests were administered in separate sessions. First, a test for passive vocabulary knowledge was administered individually. For 98 items, children had to point to one out of four pictures that corresponded to the word that was spoken by the researcher. Then, knowledge of letters and words was tested. A sheet with 27 randomly ordered lowercase letters (including the typical Dutch *ij*) was presented, and children were asked to point to any letter they knew. They were encouraged to proceed until it was obvious that no more letters were familiar. The number of letters correctly named or sounded was noted. Also, a list of 10 simple CVC words that are frequently used in beginning reading instruction was presented, and children were asked to attempt to read these aloud. There were no time constraints for the test of letter knowledge or for the test of word reading.

A test for auditory blending skill was individually presented. This test consisted of 52 items varying in size and number of segments. Ten categories of items were presented (here, dashes within the examples indicate segment separators):

1. Two- or three-syllable words—for example, *ja–rig* ("having a birthday") and *za–ter–dag* ("Saturday").
2. CV or VC words—for example, *t–oe* ("to") and *a–f* ("off").
3. C–VC words—for example, *g–eit* ("goat").
4. CV–C words—for example, *me–t* ("with").
5. CC–VC words—for example, *st–ip* ("dot").
6. CV–CC words—for example, *do–rp* ("village").
7. C–V–C words—for example, *l–ie–f* ("sweet").
8. C–C–V–C words—for example, *t–r–e–k* ("pull").
9. C–V–C–C words—for example, *g–e–l–d* ("money").
10. C–C–V–C–C words—for example, *k–r–a–n–s* ("wreath").

The first two categories consisted of 6 items each (12 items) and the other 8 categories had 5 items each (40 items). Each item was scored correctly when the child made a full blend of the presented segments. The test was stopped after completing the Category 6 items when there were more than 10 errors (out of 32 items). Analysis of the data indicated that the test appeared to be internally highly consistent (Cronbach $\alpha = .95$).

Finally, a test for phonemic segmentation of words was presented. Twenty words of increasing length and complexity of phonological structure were presented. There were 2 VC, 2 CV, 4 CVC, 4 CCVC, 4 CVCC, and 4 CCVCC words. The child was asked to articulate audibly all the different pieces of a word in the correct order. Incomplete or partial segmentation was considered as incorrect. When 3 errors occurred consecutively, the test was stopped. An item analysis showed that this test of phonemic analysis was reliable (Cronbach α for internal consistency = .96).

Teacher questionnaires on classroom activities. In a structured interview, the kindergarten teachers of the 12 groups involved in this study were questioned for information on their daily routines, the frequency of storytelling and book reading, individual teaching activities, use of materials, and emphasis on certain curricular components. Also, teacher manuals and student activity books were examined, and an inventory was made of the kinds of language stimulation games and activities, emergent literacy activities, and preparation for later formal instruction in arithmetic and reading. As is customary in Dutch kindergarten classrooms, no attention is devoted to recognizing letters or learning about letter–sound correspondences.

Training materials and procedure An interactive computerized package of reading exercises was developed in our department and provides a variety of engaging "drill-and-practice" exercises for children ranging from prereaders to competent readers. The programs were designed to give immediate (corrective) feedback in the learning process and were intended to be a supplement to the regular reading curriculum. Pupils were able to work independently with the program, and all of the instructions and comments were given in spoken form (high-quality digitized speech), as beginners naturally have problems in understanding written instructions and comments. For the same reason, only mouse control was required, allowing 5-year-olds to use the program without difficulty. This study used the package's phonological skills training capabilities, just one of the package's many possible functions. Four different exercises were used in this training study, and all materials were pictures and simple CVC spoken words (thus text was never used).

In this study, the computer exercises were first used to train several vocabulary items, and then that list of words was used for subsequent phonological awareness training. In the vocabulary exercises, pictures were presented on the screen along with several "ears." When an ear was clicked on, a word was heard through the headphones. Pupils were able to click on and hear the word as often as they liked. The objective of this exercise was for the child to drag the ear across the screen to the appropriate picture. The vocabulary exercises could be varied as to how many pictures or ears were displayed on the screen. One option started with one spoken word and four different pictures, another presented more spoken words and one picture only, and a third option was three or four words and an equal number of pictures. The various alternative words all sounded quite different in these first three options. Two final options of the exercises repeated the format of the latter two but used similar-sounding sets of words; the words differed in one phoneme only, and making a correct choice required very careful listening.

The next exercise was similar to the first except that the words were presented in segmented form. The pupil had to synthesize the individual sounds into one word sound in order to find the required pictured word. The separate letter sounds were presented at a rate of about one per second. The exercise used two options. In one option, four words and pictures were presented in which the word sounds were quite dissimilar; in the another option, the four words on one screen differed in one phoneme only. The position of phonemic differences were randomly varied between the beginning, medial, and final positions.

A third exercise involved a comparison of two spoken words presented sequentially. The pupil had to determine whether the two words were the same. The first word was always a whole word sound; the second word was (with 50% probability) the same word. The pupil was allowed to hear either word again. The matching response was a mouse click pointed at a "same" or "different" icon. These icons were explained first by the program; then a demonstration was given. There were four versions of this exercise. In the first version, both spoken words were presented as a whole, and the second word, when different, was quite dissimilar. The second version differed in that the second word was presented in phoneme segments. The third and fourth versions were similar to the first ones, except that different words differed in one phoneme only (in varying within-word positions).

A final exercise was a variation of a memory game. On the screen were an ear and a number of boxes (3, 6 or 9). When the ear was activated, the child heard a word, either whole or segmented. The child then had to search the boxes until a box with the same word was found (segmented if the child initially heard it whole, and vice versa). Although at the start of this exercise, sets of words were used that were dissimilar in sound, in later sessions the sets of words were quite similar in phonemic structure.

For the training in the experimental training condition, three sets of 20 CVC words were used in all of the exercises. Both dissimilar and similar subsets of words were created from this total set of words. The participants in the experimental training condition proceeded with the various types of exercises in the order as already described. The minimal number of items within one type of exercise was 20. As soon as a certain type of exercise was mastered (at least 80% correct), the program provided them with the next exercise. After the pretest, 12 weeks of training were available, and all children were allowed to work with the program in 10-min sessions two times per week.

Whereas normal control group members followed the regular kindergarten curriculum in their respective classes and participated in the pretest and posttest sessions only, computer control group members also participated in the computer work equally often as experimental training group members. They were given vocabulary training (only the first three options with dissimilar words) and the exercise with auditory comparisons (nonsegmented words only). Because the format of the exercise changed less frequently, it was decided to substantially increase the number of word items. Instead of changing in format or objective, the set of words involved was regularly altered. In total, 420 pictures and digitized word sounds were available.

For each of the seven classrooms, depending on the number of participating pupils, one or two microcomputer systems (Macintosh) were installed. After initial help by research assistants during the first week, children began their exercises on the computer and worked independently for 10 min. Because the user interface was made relatively simple, and children needed to use the mouse only for moving the cursor and clicking on objects, most children could proceed on their own after one or two sessions. The 10-min limit of individual sessions was chosen both because of the limited attention span of kindergartners and because everyone would have good opportunity to do two sessions each week. After the teacher started the computer, a screen with all of the pupils' names (in a large and familiar typeface) appeared. Children clicked on their own name (all could recognize at least their own name). Data were kept for each pupil individually, also allowing the program to start the next session at the point where it was left after an earlier session.

Posttests. As a first posttest, an auditory blending task and a segmentation task (detailed earlier) were readministered, but actual items were different (Cronbach αs for consistency = .97 and .92, respectively). None of the items in the pretests and posttests for phonological skills were included in the training program. The first posttests were administered after the computer training sessions were finished in kindergarten and before summer break (June).

After summer break, children entered Grade 1, in which formal instruction in reading and writing began. In Grade 1, within each school, participants were rearranged into new groups with new teachers. Although we did not have any influence on these rearrangements, the assignment to new groups appeared to be nicely balanced with respect to experimental history (experimental vs. control condition; kindergarten teacher activities on phonemic awareness).

After about 10 weeks of formal beginning reading instruction in Grade 1 (early November), an experimental decoding test was administered. The test consisted of two lists of 35 simple CVC words each. Each list was presented individually, and the participants were asked to read as accurately and as many words as they could during 1 min. The number of words correctly read was noted. The Pearson correlation coefficient for individual scores on the two lists was .89, indicating that individual differences in decoding skill were measured quite reliably. As decoding was scored, the average of these two scores was taken.

After about 18 weeks of reading instruction (early January), a posttest was administered. In individual sessions, a standardized decoding test was presented in which participants were asked to read aloud a graded list of 116 words as fast and accurate as possible within 1 min. The score was the number of words correctly read within 1 min. The items of this test were not frequent words in the reading methods used at school, so performance on this test could readily be taken as an indication of decoding ability. The decoding scores correlated .80 with the decoding scores measured 8 weeks before. Also, in a standardized, group-administered spelling test, 15 words were dictated orally. The words were graded in difficulty, starting with a simple VC word and a simple CV word and ending with two CCVCC words. The spelling score was the total number of words spelled completely correctly (maximum = 15). No reliability was measured for the present sample, but reliability estimates from other unpublished research for this test are well above .80. Finally, the blending and segmentation tests that were administered during the pretest (1 year before) were presented again. Cronbach alphas for internal consistency were .95 and .91, respectively, for the blending and phoneme segmentation tests.

RESULTS

Presented first are the data of the pretests and of the training sessions for the experimental training and computer control conditions in kindergarten. Then, the results of assessing phonological skill during the posttest in kindergarten are presented. Finally, the follow-up results of the same children in Grade 1 are presented.

Questionnaires and Pretests

Analyses of the parent questionnaires regarding the literacy environment at home showed that there were no significant differences between the experimental groups with regard to these variables, and no relation was found between any of the variables and the various pretest scores or the gains in phonological skills and reading ability during this longitudinal study.

Analyses of the results of the questionnaires for teachers showed that, although teacher activities differed in many details, only one variable appeared to be related to initial blending ability. The one exception concerned whether phonemic awareness activities were presented on a regular basis. As confirmed through observations of daily classroom routines by research assistants, there were clearly two distinct groups of teachers. Four teachers appeared to present their pupils with segmentation and blending activities on a fairly regular schedule (but certainly not more frequently than once a week), whereas, with the other 8 teachers, these activities were absent or occurred only occasionally. The 4 teachers who were active in encouraging phonological skill development were all at schools where computers were installed for the purpose of this study. Because these 4 groups were part of the two computer conditions, and an effect of this specific teacher activity could be expected, the data were split according to the presence or absence of teacher activities toward phonological development (teacher-led instruction in phonological awareness = TA+ or TA–).

The results of the pretests appear in the top half of Table 1. Whereas the summary data of the normal control group are preserved in Table 1 to allow for overall comparisons, in the statistical analyses this control group was discarded because, as previously argued, it does not constitute a proper control group for evaluating the effects of the specific training conditions and because within this group none of the teachers was active in instructing phonemic awareness.

Analyses of variance were performed to test for significant differences in pretest scores between conditions. The scores for the vocabulary test—the mean number of correctly identified letters (either names or sounds) and recognized words—did not differ significantly between the experimental conditions. For the blending scores, a significant Experimental Condition × Teacher Activities interaction appeared, $F(1, 49) = 5.49, p < .05$, indicating that the children in the com-

TABLE 1
Mean Scores and Standard Deviations for the Various Tests as a Function of Experimental Condition and Time of Testing

Stage and Tests	Number of Items		Normal Control TA–[a]	Computer Control TA+[b]	Computer Control TA–[c]	Experimental Training TA+[d]	Experimental Training TA–[e]
Pretests in kindergarten							
Vocabulary test	98	*M*	54.0	59.3	50.4	54.2	54.7
		SD	18.1	22.4	20.5	14.6	20.2
Letter sounds	27	*M*	4.1	4.5	4.2	5.4	3.5
		SD	4.1	4.0	3.9	4.2	3.4
Recognizing words	10	*M*	0.2	0.6	0.0	0.6	0.5
		SD	0.4	1.1	0.0	1.2	0.6
Blending	52	*M*	14.2	18.7	12.6	11.0	13.1
		SD	5.6	9.3	4.1	5.4	4.8
Segmentation	20	*M*	1.8	6.1	1.1	2.7	0.8
		SD	3.7	7.2	2.2	4.2	1.5
Posttests at end of kindergarten							
Blending	52	Observed *M*	18.9	29.3	16.7	27.7	24.1
		SD	10.9	11.8	9.3	13.5	10.9
		Adjusted		23.7	18.1	31.0	25.0
Segmentation	20	Observed *M*	3.9	9.6	2.9	6.5	5.6
		SD	4.7	6.8	4.7	5.6	5.5
		Adjusted		7.1	4.1	6.5	7.1
Posttest after 10 weeks in Grade 1							
Decoding (CVC)	35	Observed *M*	9.1	9.8	7.4	10.4	11.7
		SD	5.2	5.3	3.9	5.7	10.3
		Adjusted		8.2	7.3	10.6	13.3
Posttests after 18 weeks in Grade 1							
Decoding (graded)	116	Observed *M*	10.1	11.6	9.5	12.0	14.4
		SD	4.8	5.4	3.9	3.7	7.4
		Adjusted		11.2	8.9	11.9	15.5
Spelling	15	Observed *M*	10.0	12.0	10.4	11.0	10.1
		SD	3.7	3.8	2.5	3.4	3.7
		Adjusted		11.4	10.4	11.0	10.7
Blending	52	Observed *M*	39.8	44.7	40.6	44.9	45.1
		SD	11.0	7.3	8.9	4.5	6.0
		Adjusted		43.1	41.1	45.9	45.4
Segmentation	20	Observed *M*	15.4	16.3	15.3	14.2	14.9
		SD	4.6	3.8	4.4	5.6	5.6
		Adjusted		15.5	15.7	14.2	15.4

[a]*n* = 45 children. [b]*n* = 14 children. [c]*n* = 14 children. [d]*n* = 11 children. [e]*n* = 14 children.

puter control group who were in classrooms with teacher support for development of phonological awareness scored significantly higher on the blending test than all the other groups did. For the segmentation scores, a significant main effect of teacher support was obtained, $F(1, 49) = 7.95$, $p < .01$, demonstrating that the scores for segmentation were higher in classrooms in which teachers were promoting phonological awareness. Neither an effect of experimental condition nor a significant interaction effect was found in the analysis of segmentation scores on the pretest.

Training Sessions

Generally, children were quite eager to be engaged in the computer program, so they did not object at all to the teachers' attempt to keep the schedule of twice a week for each pupil. The participants in the experimental training condition did computer exercises for an average of 19.9 sessions. Because each session lasted about 10 min, the mean time they were involved in the computer-assisted training in blending skill amounted to 3 hr, 20 min. About 7% of the total time was used to complete the exercises in which discrimination of similar-sounding whole words was needed, and 67% of the total time was used to work at exercises in which blending was explicitly required. The remaining 25% of the time was used to introduce vocabulary items and also included time spent for the other exercises in which no explicit blending or analytic skills were required. The participants in the computer control condition finished, on average, 17.9 sessions, which amounts to about 3 hr.

In general, participants greatly enjoyed the computer-assisted exercises both in the experimental training and computer control conditions. The average proportion correct during training sessions was well above 80%. All participants were continuously highly motivated, and many expressed sincere regret that the computers, after being used for 12 weeks, would be (temporarily) removed from the classrooms.

Phonological Skills at the End of Kindergarten

Mean scores for the blending and the segmentation tests at posttest in kindergarten are also presented in Table 1. An analysis of covariance (ANCOVA) with pretest scores as the covariate was done. The pretest scores accounted for 40.2% of the variance of the posttest scores on the blending test, $F(1, 48) = 32.28$, $p < .01$. The ANCOVA showed a significant effect of condition, $F(1, 48) = 7.72$, $p < .01$. Observing that means are statistically different does not really tell us anything about the relative impact of the specific training. Therefore, the effect size η^2 (partial η^2) for this condition effect was calculated. This measure of effect size can readily be interpreted as the amount of variance accounted for by the training. The effect size for the difference between the experimental training and the computer control groups was .139 (i.e., 13.9%, which corresponds to a perhaps more familiar Cohen's d of .80). The dichotomous variable of teacher activities also resulted in a significant effect, $F(1, 48) = 5.43$, $p = .02$, $\eta^2 = .102$. No interaction effect was found between these two factors ($F < 1$), and inspection of the Table 1 data indeed indicates that teacher activities and experimental computer condition are additive effects.

An ANCOVA for the segmentation scores again revealed a significant effect of pretest scores (34.3% of the posttest scores was accounted for by the pretest scores), $F(1, 48) = 25.02$, $p < .01$, but no significant effects of experimental condition or teacher activities and no interaction effect were found for the posttest scores on the segmentation test.

Grade 1 Posttests

The mean scores on the decoding test administered after 10 weeks of initial reading instruction in Grade 1 appear next in Table 1. The decoding scores are, on average, the highest for the pupils who received experimental training in kindergarten. An ANCOVA with the pretests at the beginning of the study as covariates was carried out. Together, these variables accounted for 28.9% of the variance in decoding performance, $F(5, 44) = 3.59$, $p < .01$. The analysis revealed a statistically significant difference between the experimental training group and the computer control group, $F(1, 44) = 5.18$, $p = .03$, $\eta^2 = .105$. No effect of teacher activities in kindergarten could be discerned on the decoding scores ($F < 1$), and no interaction between training condition in kindergarten and teacher activities could be discerned ($F = 1$).

The averaged results for the various tests obtained after children had received 18 weeks of formal instruction in reading appear at the bottom of Table 1. An ANCOVA with the pretests of 1 year before as covariates was done. This time, the combined set of variables accounted for 20.5% of the variance in decoding scores, $F(5, 44) = 2.27$, $p = .06$. The analysis further disclosed, again, a significant main effect of experimental training condition, $F(1, 44) = 5.56$, $p = .02$, $\eta^2 = .112$, but no main effect of teacher activities in kindergarten ($F < 1$) was obtained. The interaction effect between the two factors was also not significant, $F(1, 44) = 3.59$, $p = .07$. This finding demonstrates that the computer-assisted training of blending skills in kindergarten has at least a medium effect ($d = .71$; Cohen, 1988) on decoding proficiency.

A similar ANCOVA for the spelling results did not reveal any significant effect (Fs < 1). An ANCOVA for the scores on the blending test with the pretest as a covariate also showed no significant effects, experimental training condition, $F(1, 49) = 3.38$, $p = .07$, or other effects (Fs < 1). Similarly, for the segmentation test scores, no significant effects were obtained (all Fs < 1). Performance on the latter tests seemed to approach ceiling levels, however, and this may have prevented differential condition effects from appearing.

DISCUSSION

This study was an attempt to replicate the findings of several previous studies—namely, that training can influence the development of phonological skills in young, preschool children. More specifically, the study aimed to answer the question whether it is possible to use a computer program to improve the ability of kindergartners to synthesize phoneme-size segments into a single word sound. The results show that the group of children that received computer-assisted practice in kindergarten gained significantly more in blending skill than children in the control group. The size of the training effect was substantial (13.9% of the variance was accounted for by experimental condition). These results are in agreement with others' findings that phonological skills can be trained in preliterate children (e.g., Olofsson & Lundberg, 1983) and demonstrate that it is quite possible to use a computer program to significantly increase young children's blending skill.

This study thus confirmed Foster et al.'s (1994) finding that experience with a high-quality interactive computer program can enhance phonological awareness in young children. The present study, however, significantly added to this previous research by including a more appropriate control group, by taking the classroom environment into consideration, and by posttesting the children after they received a few months of beginning reading instruction. Foster et al.'s control group received no treatment at all, whereas our control group was equally involved with the same computer program without the presentation of specific blending exercises. Comparison of a treatment group and an untreated control group may be confounded by unknown or uncontrolled variables, whereas comparison with a more appropriate control group, like our computer control group, is generally accepted to be a more adequate design. Foster et al.'s findings, however, are certainly confirmed by the results of the present, more rigorous research design.

More important, this study's extension of previous research—considering teachers' activities with respect to promoting phonological awareness—turned out to be important. Four of the 12 teachers regularly appeared to encourage pupils in their classes to analyze or to blend speech sounds within their language stimulation activities, whereas in the remaining classes segmentation and blending activities occurred rarely or were absent. This specific instructional context was unknown before the experiment was designed and started. The findings, however, reveal that these teachers' activities have a significant effect on phonological skills at the beginning of this study and on the blending skills at the end of kindergarten. Although the differences in instructional classroom environment could well have masked the possible effects of computer training, the present results clearly show that the effects were additive, because no interaction was found. The adjusted means show that the group of children who both received instructions by their teachers and had specific training on the computer outperformed all other groups. In this context, it is worth noting that, with regard to growth in phonological skills during kindergarten, the results of the computer control group with no teacher support are quite similar to those of the normal control group with no teacher support.

The present research findings do not suggest that computer exercises have more potential or advantages over teacher-led instruction. A fair and valid comparison between computer-assisted versus teacher-led instruction is extremely difficult to make, and one can seriously question the usefulness of such a contrast (cf. Reinking & Bridwell-Bowles, 1991). A more fruitful and realistic approach would probably be to examine whether computer-assisted exercises can have additional value to regular teacher-led classroom activities. Among the potential advantages of computer-assisted instruction and practice are that they do not require much teacher time and that there is less variability in quality of instruction and exercises. The present results indicate that the computer program indeed had extra benefits to teachers' activities, irrespective of whether teachers incorporated on a regular basis phonemic awareness training in their daily activities. But, of course, further improvements in teacher-led activities may also produce substantial growth in phonological skills in kindergarten. Perhaps a combination of teacher-led instructions and computer-assisted practice will be the most effective strategy, as the present findings suggest.

A final issue was whether beneficial effects of training in blending can be found on progress in learning to read. In this study, it indeed was found that higher skill in blending affected subsequent acquisition of reading skills. The higher blending skills at the end of kindergarten probably enabled the children from the experimental training group to make a better start in acquiring decoding skills in Grade 1—that is, for acquiring the first self-teaching procedures (Share, 1995). After 10 weeks of instruction, a statistically significant effect of experimental condition on decoding skill was established. The adjusted decoding scores in Table 1 definitively show an advantage for the children who received computer-assisted training in blending. However, no effects of the activities of kindergarten teachers in stimulating phonemic awareness could be found. Because the experimental training was carried out before formal instruction in reading, the findings have again added support for the view that phonological awareness is a causal skill in early reading acquisition. Six months after the start of initial reading instruction, the experimentally trained group of children was also significantly better in decoding performance than the children who participated in the computer control condition, although the training effect perhaps needs to be qualified by a trend toward an interaction with teachers' activities in kindergarten. Comparison of adjusted means shows that the effect of computer training is primarily observed with the children originating from kindergarten classrooms in which the teacher did not instruct phonological awareness. It is not clear what caused this trend toward an interaction, but we resist the temptation to speculate on possible causes because no control for teachers activities was made during Grade 1 reading instruction.

One could well argue that control for teachers' instructions is very important in evaluating effects of interventions. Differences in reading achievement are to some extent also related to instructional factors and would constitute a confounding factor for determining the longer term effects of kindergarten training. With respect to this line of reasoning, it is worth noting that none of the published studies on the effect of phonological training on later reading ability controlled for factors concerning the quality of reading instruction. In particular, when different schools are involved in treatment or control conditions, one might expect carryover effects on later reading instruction. Grade 1 teachers at a particular school or in a local area cannot of course be kept completely in the dark about an intensive kindergarten program designed to stimulate the development of phonemic awareness. Learning about the rationale and eventual successes of the program, teachers may adapt their instructions in beginning reading in important ways. For example, perhaps as a consequence of the previous training in kindergarten, the reading instruction for experimental and control classes in Lundberg et al.'s (1988) study may have differed too. In our study, no obvious criterion was available to the teachers to classify their pupils as ones who had received specific computer training in kindergarten or not. The present experimental and computer control participants by and large received the same instructions in beginning reading, because they were all (mixed) in the same classes and had the same teachers. Further, the teachers used the same method for reading instruction and generally seemed to strictly follow the instructions, guidelines, and materials provided by the reading method. Within the context of emphasizing the communicative role of written language, the reading method strongly focuses on direct instruction of phonological skills such as segmentation and blending of letter–sound correspondences and decoding (cf. Reitsma & Verhoeven, 1990). Although there is insufficient reason to believe that important differences in educational context could hinder the interpretation of the present findings, there might have been small but important differences in instructional factors leading to another source of differences in decoding ability halfway through Grade 1.

It is important to note that the gain in scores on the blending and segmentation tests were two or three times as large in the first 6 months of Grade 1 than the gain in kindergarten. The difference is even more striking when the structure of the tests is taken into account (items gradually increase in difficulty). One cannot escape the conclusion that beginning reading instruction has been the major force behind these substantial improvements in phonological skills. Phonological skills were directly taught in conjunction with grapheme–phoneme correspondences and decoding procedures in initial reading instruction. However, if initial reading instruction can have such a pervasive influence on the development of phonemic awareness, then one could also argue that it may strongly counteract effects of initial differences. Consequently, the effect of individual differences in phonemic awareness that exist before reading instruction on later decoding performance may be considerably diminished. Besides possible ceiling effects, this may also be the reason why differences in blending skills between experimental groups were no longer reliable in Grade 1. On the other hand, when classroom instruction does not explicitly draw attention to the alphabetic principle and the correspondences between segments of script and speech (e.g., in whole word methods), a much larger effect of initial differences in phonological skills can be expected, and pretraining of kindergartners in phonological skills may be more profitable (e.g., Kozminsky & Kozminsky, 1995). If this line of reasoning is sound, then the present results are even more remarkable in showing an effect of training in kindergarten on later decoding ability. But, again, it also strongly suggests the necessity of including information on the type and quality of reading instruction in research comparisons of the effects of phonological skill training.

Finally, although the training resulted in improved blending skill, no effects were found on segmentation skill. Moreover, the training in blending had an effect on later reading ability, whereas differences in spelling ability between conditions were not observed. These findings, then, do not challenge the view that blending contributes mainly to decoding, whereas spelling is more dependent on segmentation skill. However, research also suggests that teaching both segmentation and blending is most beneficial for decoding development, because it encourages a more complete, decontextualized understanding of the phonemic structure of words than training in only one of the skills (e.g., Fox & Routh, 1984; O'Connor, Jenkins, & Slocum, 1995; Torgesen, Morgan, & Davis, 1992). Thus, although this study shows that training only in blending also facilitates learning to read, training the combination may actually be most productive (i.e., positively affecting the subsequent acquisition of both reading and spelling).

The present results can be seen as encouraging for educational applications of computer technology for learning to read. All of the children certainly much appreciated the exercises. Although previous research has already demonstrated the benefits of using programs with capabilities of computer-generated speech for advancing reading skills in beginning or disabled readers (e.g., Barker & Torgesen, 1995; Elbro et al., 1996; Foster et al., 1994; Olofsson, 1992; Olson & Wise, 1992; Reitsma, 1988; Spaai et al., 1991; Van Daal & Reitsma, 1993), this study and the research by Barker and Torgesen (1995) and Foster et al. (1994) show that computer-assisted exercises can also profitably be used in preparing kindergartners for later instruction in reading.

In conclusion, the results of the present longitudinal study lend strong support to the conjecture that training of blending operations before the introduction of letters and printed words may help children acquire initial decoding skills. Use of computer-assisted exercises for the training of blending skills appeared to be quite successful, and further investigations concerning both the short- and long-term effects of the educational use of computers for initial reading development are warranted.

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